ELECTRICAL AND MECHANICAL PROPERTIES OF LEAD/TIN SOLDERS AND SPLICES AT 4.2 K

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An experimental investigation of lead/tin solders and splices has been made for the coil conversion of Fermilab's 30" Bubble Chamber Magnet. The electrical resistivities of various lead/tin solders were measured at 4.2 K in a variable magnetic field. Correlations for the magneto-resistivity of the solders have been developed. Electrical measurements on the splices determined their resistance and voltage distribution. Comparative stress-strain experiments on solders and splices have shown adequate solder tensile strength is not as important as preventing a peeling failure mechanism. General guidelines for splice preparation are given.

INTRODUCTION

Splices for Cu stabilized NbTi superconducting cable must have reasonable voltage drops and satisfactory mechanical properties. Tests at Fermilab showed that large numbers of low resistance high strength splices could be made quickly and reliably with a clamping fixture and ordinary lead/tin solders.

MAGNET, CONDUCTOR AND SOLDERS

Seventeen splices each 60 cm long were wound into Fermilab's 30" Bubble Chamber Magnet. The maximum field in the windings is 5.0 T at an operating current of 675 amps. Mechanically strong splicing was an absolute requirement since the conductor maximum hoop stress is 165 MPa. The magnet is described more fully elsewhere [1].

The conductor is a copper stabilized NbTi cable with a Cu/SC ratio of 9.8. It consists of a central rectangular copper core surrounded by 6 Energy Doubler strands and 8 copper strands and impregnated with 50 Pb/50 Sn solder. The overall dimensions of the cable are 2.3 mm x 4.6 mm.

The solders used were commercially available solid wires conforming to ASTM specification B32 or Federal specification QQ-S-571 in composition. The five compositions tested were pure lead, 60% lead, 50% lead, 40% lead, and pure tin. All splices were prepared using a specially built electrically heated aluminum soldering fixture [2]. The splices were made edge to edge. In all cases an activated noncorrosive rosin flux, Kester SP 44 was used.

(a) Electrical Measurements

A 5 Tesla magnet 35 cm long by 6 cm ϕ was fabricated. Five solder samples were mounted parallel to the axial field, and one sample was mounted perpendicular to the field. The resistivity was measured using the four point technique. Voltage drop across the 8 cm long by 3.2 mm samples was monitored with a Hewlett Packard model 419A DC null voltmeter.

Splice samples were all oriented parallel to the field so that the actual current transfer across the splice measured the worse case transverse magnetoresistivity. Voltage taps were soldered to the samples along their length and rigidly fixed to prevent spurious voltages due to wire movement.

(b) Mechanical Measurements

The solder samples were fabricated from 3.2 mm diameter solid wire by pressure molding the central portion. This technique was found effective in promoting specimen neck down and failure between the gage marks. All samples were air annealed a minimum of 12 hours at 100^0C after molding. Figure 1 shows the specimen dimensions. The stress strain curves were taken with a special fixture. Strain was measured using a MTS model 632,11B-21 axial extensometer and a Strainsert model TN8C readout. The manually applied load was measured with a BLH Model C3P1 load cell and a model 450A readout. The splices were tested with the same fixture in a bath of liquid nitrogen.

RESULTS

(a) Electrical

Electrical resistivity of the 5 solder compositions in a magnetic field is shown in Fig. 2. Measurements made on 50/50 PbSn samples in transverse and axial fields showed no appreciable differences in magnetoresistivity. Correlations developed for resistivities are given in Table 1. Their range of applicability is 0.3 T to 5 T.

Table 1. Solder magnetoresistivities at 4.2 K in an axial field.

Composition	Correlation $\rho(\Omega\text{-m}), B(T)$
Pure lead	$\rho = 0.05 \times 10^{-9}\ (1 + 0.16\ B)$
60 Pb/40 Sn	$\rho = 6.52 \times 10^{-9}\ (1 + 0.010\ B)$
50 Pb/50 Sn	$\rho = 5.90 \times 10^{-9}\ (1 + 0.0081\ B)$
40 Pb/60 Sn	$\rho = 5.40 \times 10^{-9}\ (1 + 0.0089\ B)$
Pure Tin	$\rho = 0.83 \times 10^{-9}\ (1 + 0.157\ B)$

The electrical resistance of several splices made with 40 Sn/60 Pb solder were measured in a magnetic field. The lengths measured were 6.2 cm, 24 cm and 32.7 cm. Their respective resistances at 5 T were 0.048 μΩ, 0.011 μΩ and 0.010 μΩ. Voltage taps along the current transfer region showed equipotential voltages. These results suggest the splice's resistance is due to the solder's resistivity. Splice resistance is a function of length and solder thickness. The splices tested all showed magnetoresistivity trends similar to the solders.

(b) Mechanical

The full strength of the cable could easily be realized with short (< 10 cm) splices if both ends of the splice were banded with fine copper wire as shown in Fig. 1. The bands prevent a premature peeling failure mechanism. The stress-strain behavior of the five solders is shown in Fig. 3. As expected, higher lead content increases ductility, decreases strength and decreases modulus. The accompanying table lists the significant mechanical properties. Pure tin samples showed wide variability in tensile strength probably due to notch sensitivity.

(c) General Splicing Guidelines and Recommendations

The soldering fixture produced uniform splices with various operators and kept tight tolerances on the splice dimensions. Activated rosin fluxes are recommended over zinc chloride based fluxes which can lead to corrosion. The splicing procedure consisted of sandwiching a length of rosin core solder between the two flux coated wire ends, heating and then tightening bolts to press the wire together. Banding the splice ends was found to be highly successful. 40 Sn/60 Pb alloy is the preferred choice although 50/50 would be a reasonable alternative. Both of these alloys possess excellent wettability and low melting points with very similar 4.2 K tensile strengths. However, the 40 Sn alloy has nearly twice the 4.2 K elongation of the 50 Sn alloy. Higher tin percentage solders are not recommended due to their lack of ductility at 4.2 K.

REFERENCES

1. Craddock, W., Kephart, R., Kobayashi, M., Mruzek, M. and Pless, I., "Coil Conversion of the Fermilab 30-inch Bubble Chamber Magnet." To be published in Advances in Cryogenic Engineering, Vol. 27 (1981).

2. Mruzek, M., "Properties and Methods of Lead/Tin Splices for Superconductors", Fermilab TM-944, (Sept. 1980).

TABLE 2 MECHANICAL PROPERTIES OF LEAD-TIN SOLDERS

CURVE	%Sn	TEMP ^{o}K.	σu (MPA)	σy (MPA)	ELONGATION %
A	100	4.2	>196	-	∿0.5
B	60	4.2	173	149	1.2
C	50	4.2	171	132	3.0
D	40	4.2	158	102	5.6
E	0	4.2	80	11	34.5
-	100	77	>132	-	∿1
F	60	77	124	90	5.6
G	50	77	114	89	6.0
H	40	77	105	79	11.9
-	0	77	38	-	17.8

FIG. 1

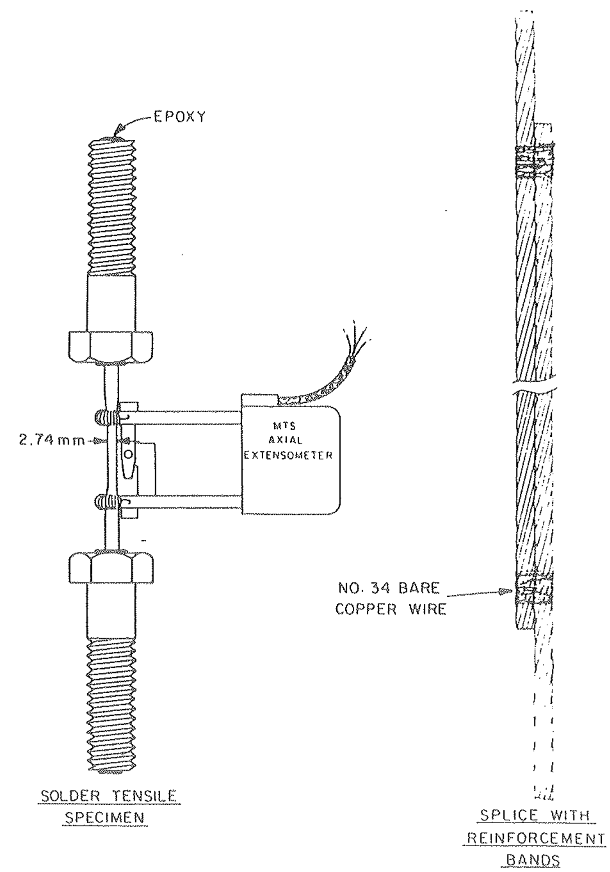

FIG. 2 COMMERCIAL SOLDER RESISTIVITIES IN A MAGNETIC FIELD AT 4.2 K.

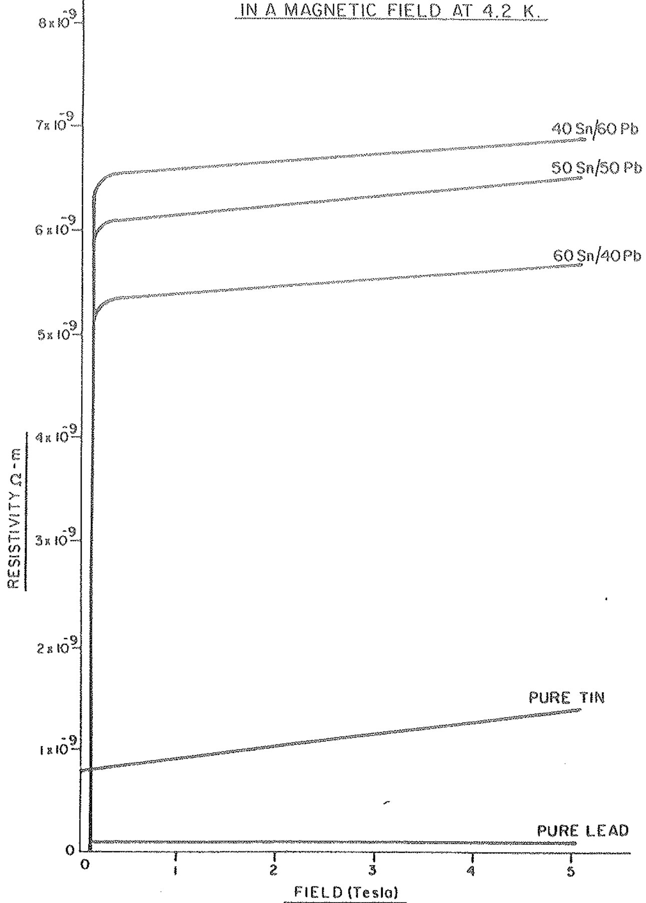

FIG. 3 STRESS-STRAIN CURVES OF VARIOUS SOLDERS AT 77 K AND 4.2 K